Modal Mapping Techniques for Geoacoustic Inversion and Source Localization in Laterally Varying, Shallow-Water Environments

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LONG-TERM GOALS

The long-term goal of this research is to increase our understanding of shallow water acoustic propagation and its relationship to the three-dimensionally varying geoacoustic properties of the seabed.

OBJECTIVES

The scientific objectives of this research are: (1) to develop high-resolution methods for characterizing the spatial and temporal behavior of the normal mode field in shallow water; (2) to use this characterization as input data to inversion techniques for inferring the acoustic properties of the shallow-water waveguide; and (3) to use this characterization to improve our ability to localize and track sources.

APPROACH

An experimental technique is being developed for mapping the normal mode field and its wavenumber spectrum as a function of position in a complex, shallow-water waveguide environment whose acoustic properties vary in three spatial dimensions. By describing the spatially varying spectral content of the modal field, the method provides a direct measure of the propagation characteristics of the waveguide. The resulting modal maps can also be used as input data to inverse techniques for obtaining the laterally varying, acoustic properties of the waveguide. The experimental configuration consists of a moored, drifting, or towed source radiating one or more pure tones to a field of freely drifting buoys, each containing a hydrophone, GPS navigation, and radio telemetry, as shown in Fig. 1. A key component of this method is the establishment of a local differential GPS system between the ship and each buoy, thereby enabling the determination of the positions of the buoys relative to the ship with submeter accuracy. In this manner, the drifting buoys create 2-D synthetic aperture horizontal arrays along which the modal evolution of the waveguide can be observed in the spatial domain, or after beam forming, in the horizontal wavenumber domain. In this context, two-dimensional modal maps in range *and* azimuth, as well as three-dimensional bottom inversion in range, depth, *and* azimuth, become achievable goals. In addition, these high-resolution measurements have provided significant new insights into source localization and tracking techniques.

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14. ABSTRACT
The long-term goal of this research is to increase our understanding of shallow water acoustic propagation and its relationship to the three-dimensionally varying geoacoustic properties of the seabed

15. SUBJECT TERMS

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WORK COMPLETED

Prior to 2006, three successful Modal Mapping Experiments (MOMAX) were completed. Two of these experiments (MOMAX I and SWAT/MOMAX III) were conducted in the East Coast STRATAFORM/SWARM area off the New Jersey coast and one (LWAD 99-1/MOMAX II) was carried out in the Gulf of Mexico. In these experiments, several drifting MOMAX buoys received signals out to ranges of 20 km from moored, drifting, and towed sources transmitting pure tones in the frequency range 20-475 Hz. In the traditional MOMAX deployment, a source transmits a pure tone (usually several) of precisely known frequency to the MOMAX buoys. The known carrier frequency contribution to the total phase is removed from the measured signal, and the resulting pressure field magnitude and phase versus time data are then merged with the corresponding GPS-derived source-receiver positions versus time. This procedure enables the determination of the pressure magnitude and phase as a function of two-dimensional position. High-resolution beam-forming techniques (corresponding to the application of an asymptotic Hankel transform) and inverse methods are then applied to these synthetic aperture data to obtain the modal information and the geoacoustic properties of the seabed.

On Aug. 30 – Sept. 5, 2006, MOMAX IV was successfully conducted as part of SW06, the ONR-sponsored, multi-institutional, multi-ship, series of shallow-water experiments that were conducted off the New Jersey coast throughout the summer of 2006. A wide range of environmental data was also obtained as part of SW06 that included an extensive suite of physical oceanographic measurements. As a result, a primary focus of SW06/MOMAX IV was the study of the effects of water column variability on the modal inversion process.

SW06/MOMAX IV was conducted aboard the R/V Oceanus, which served as the source ship from which the NUWC J15-3 sound source was suspended from the A-frame at a depth of 60 m. The source transmitted pure tones for a period of approximately 25 hours with frequencies of 50, 75, 125, and 175 Hz. These signals were received by 4 drifting MOMAX buoys (each with hydrophones at depths of 40 and 43 m), as well as an 8-channel Webb vertical line array (VLA), out to ranges of 10 km. The VLA, with 8 m hydrophone spacing, was deployed during MOMAX IV on Aug. 31 and recovered on Sept. 8 on a subsequent R/V Oceanus cruise. The ship track, the trajectories of the drifting buoys, and the location of the VLA are shown in Fig. 2. Also shown are the positions of 3 environmental moorings and 3 acoustic sources that were already present in the area as part of the suite of SW06 experimental assets. This experimental site was chosen because of the proximity of these assets and the presence of subbottom river channels which introduce lateral variability into the bottom environment. The source/receiver tracks and VLA position are superimposed on the channel locations in Fig. 3. These channels are of interest because one of the major goals of this work is to determine the relative effects of fluctuations in the water column (e.g., due to internal waves) versus lateral variation in the seabed (cf. Fig. 4) on low-frequency modal propagation and geoacoustic inversion. In further pursuit of detailed water column information, both the VLA and the sound source string were outfitted with a series of temperature sensors. In addition, each MOMAX buoy was equipped with two temperature sensors and one temperature/pressure sensor. These measurements clearly indicate that the most dynamic portion of the water column is the thermocline at 20-40 m depth, where internal wave effects are expected to be concentrated.

RESULTS

An example of 50 Hz data obtained on one of the buoys (Larry) is shown in Fig. 5, as well as the source/receiver tracks superimposed on the subbottom river channel locations. This novel 4-quadrant display was developed in 2007 and brings us much closer to achieving the goal of visualizing the sound field and its relationship to the environment, specifically lateral variation in the subbottom geoacoustic properties. An examination of this figure suggests that the subbottom variability associated with these channels may be a cause of the pronounced variation in the measured wavenumber spectrum as a function of range. However, a preliminary analysis of other MOMAX IV data indicates a potential correlation between temperature fluctuations in the water column and the observed variations in the acoustic field. Initial observations also indicate that, in some cases, the acoustic data obtained on the upper hydrophone are more variable than the data obtained on the lower hydrophone. These results are consistent with the fact that the upper hydrophone depth (40 m) corresponds to a more dynamic portion of the water column than the lower hydrophone depth (43 m). An investigation of the dependence of this effect on buoy location and frequency has begun. Finally, an examination of various geometrical effects on low-frequency propagation is also underway.

IMPACT/APPLICATIONS

The experimental configuration consisting of a CW source and freely drifting buoys will provide a simple way to characterize a shallow water area and may be useful in survey operations. In addition, the planar, synthetic receiving array may offer an effective new technique for localizing and tracking sources of unknown, quasi-stable frequency in shallow water.

TRANSITIONS

The synthetic aperture technique and Hankel transform inversion methodology which underlie the modal mapping method have been implemented in the ACT II experiment, sponsored by DARPA and ONR, and have been used in the REMUS towed array experiments being conducted by Carey and Lynch. This approach has also been adopted by several research groups internationally, including the Japanese groups involved in SWAT.

RELATED PROJECTS

MOMAX I and III, as well as SW06, were conducted in the same area off the New Jersey coast where the ONR-sponsored STRATAFORM, SWARM, PRIMER, Geoclutter, and Boundary Characterization experiments were carried out. The extensive geophysical, seismic, acoustic, and oceanographic data obtained in this suite of experiments are being used to ground truth the MOMAX measurements.

The SW06/MOMAX IV data analysis and interpretation are being carried out in collaboration with a number of other SW06 investigators, including:

Acoustics: Kyle Becker, Ross Chapman, Harry DeFerrari, Bill Hodgkiss, David Knobles, Jim Lynch.

Geoacoustics: John Goff, Altan Turgut.

Physical Oceanography: Tim Duda, Glen Gawarkiewicz, Scott Glenn, Frank Henyey, Jim Moum, Jonathan Nash.

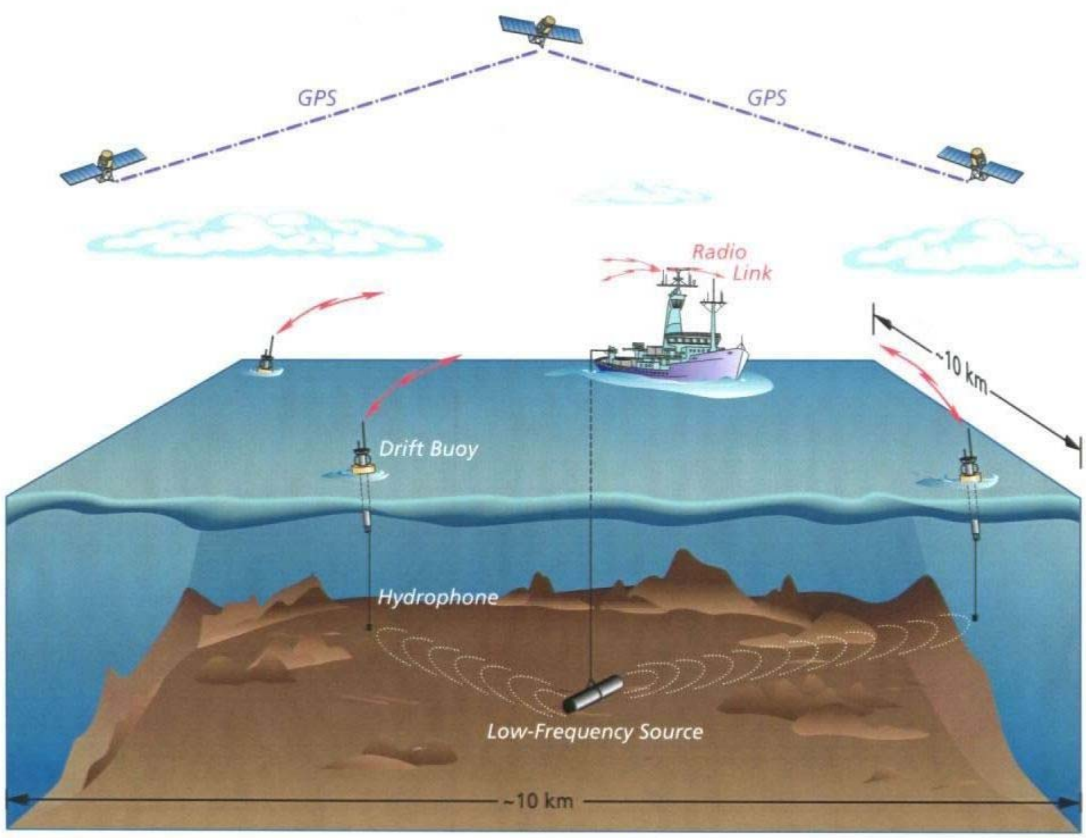

Figure 1: MOMAX experimental configuration.

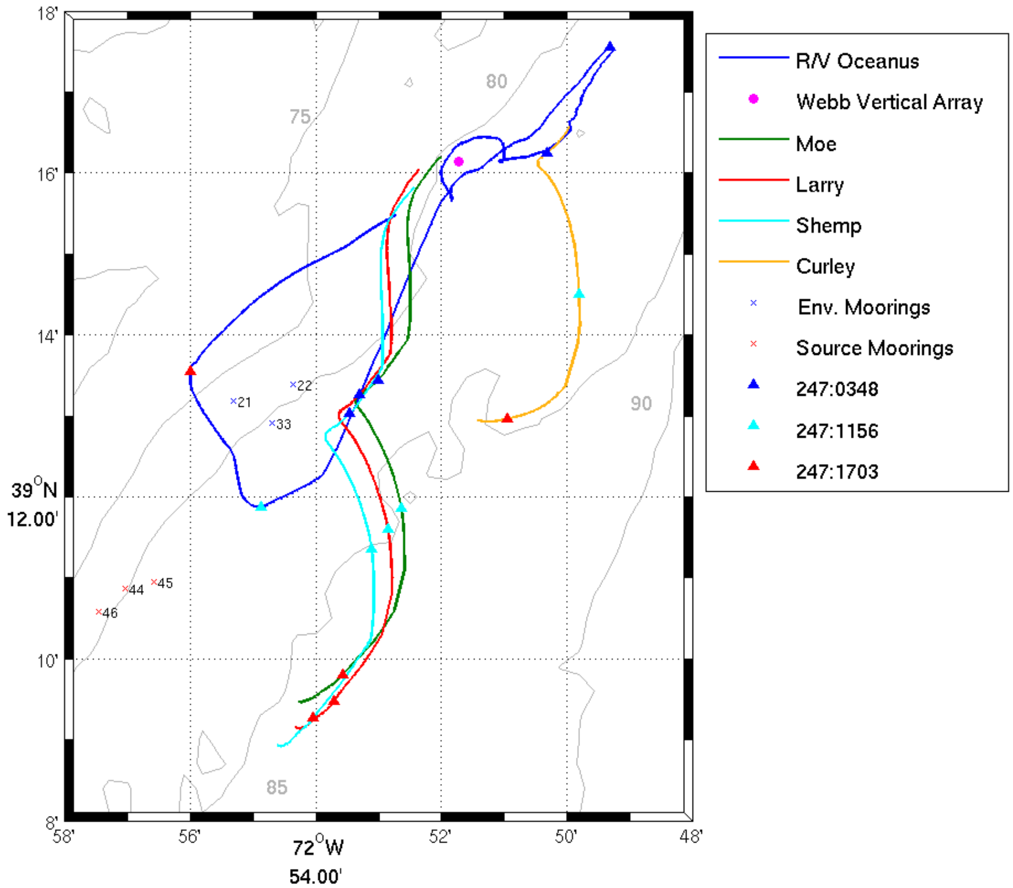

Figure 2: Tracks of source ship (R/V Oceanus) and 4 drifting buoys (Moe, Larry, Shemp, Curley) for the SW06/MOMAX IV Experiment. Also shown are the Webb VLA, 3 environmental, and 3 source moorings in the experimental area.

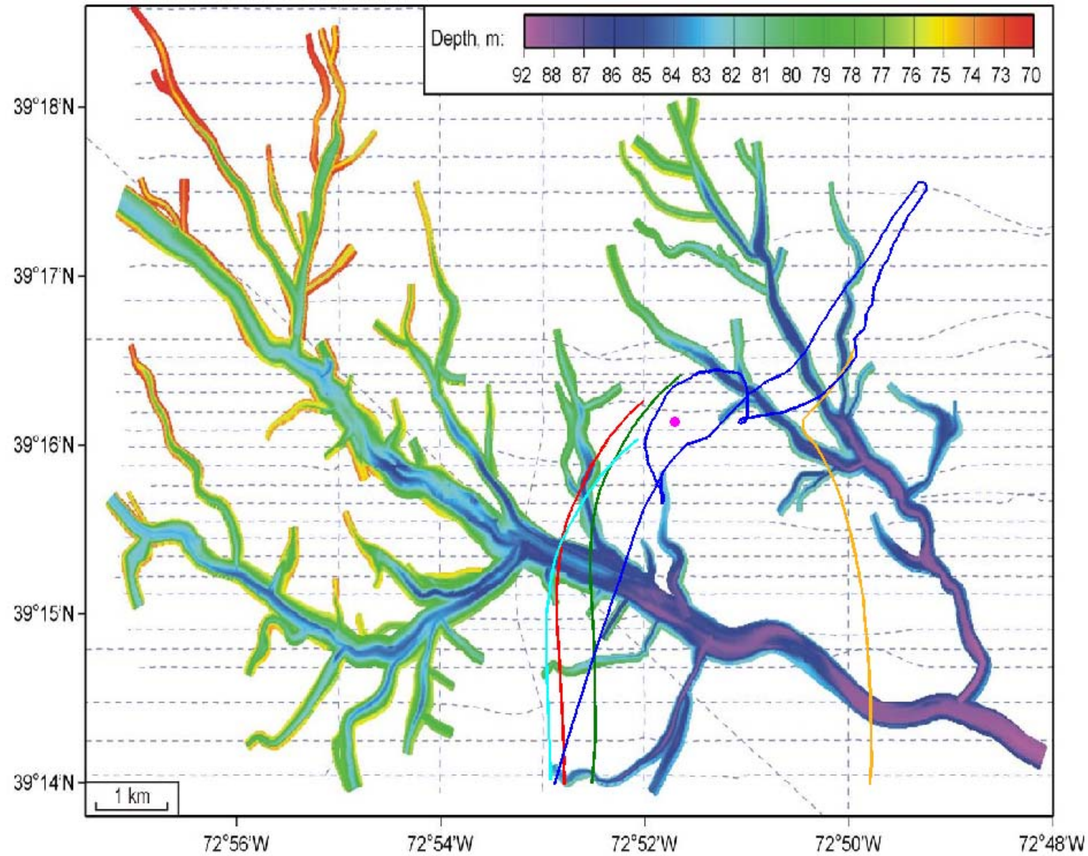

Figure 3: Tracks of source ship and 4 drifting buoys (see legend in Fig. 2) for the SW06/MOMAX IV Experiment superimposed on subbottom river channel locations (J. Goff, private communication). Also shown is the Webb VLA (red dot).

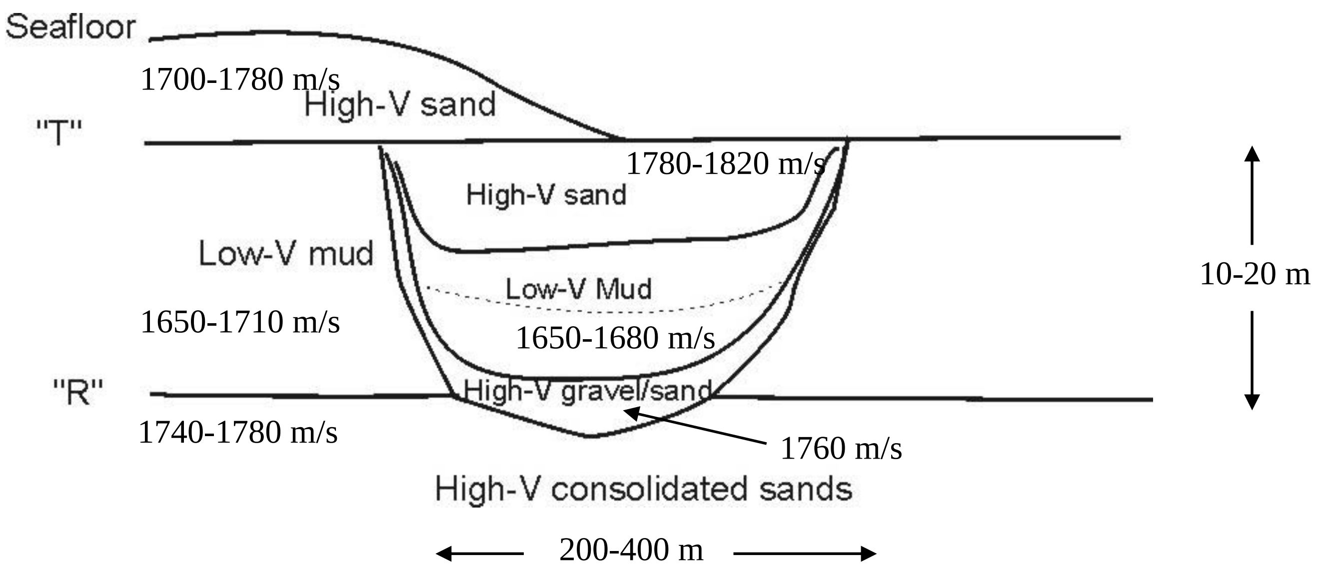

Figure 4: Typical subbottom river channel cross section (J. Goff, private communication).

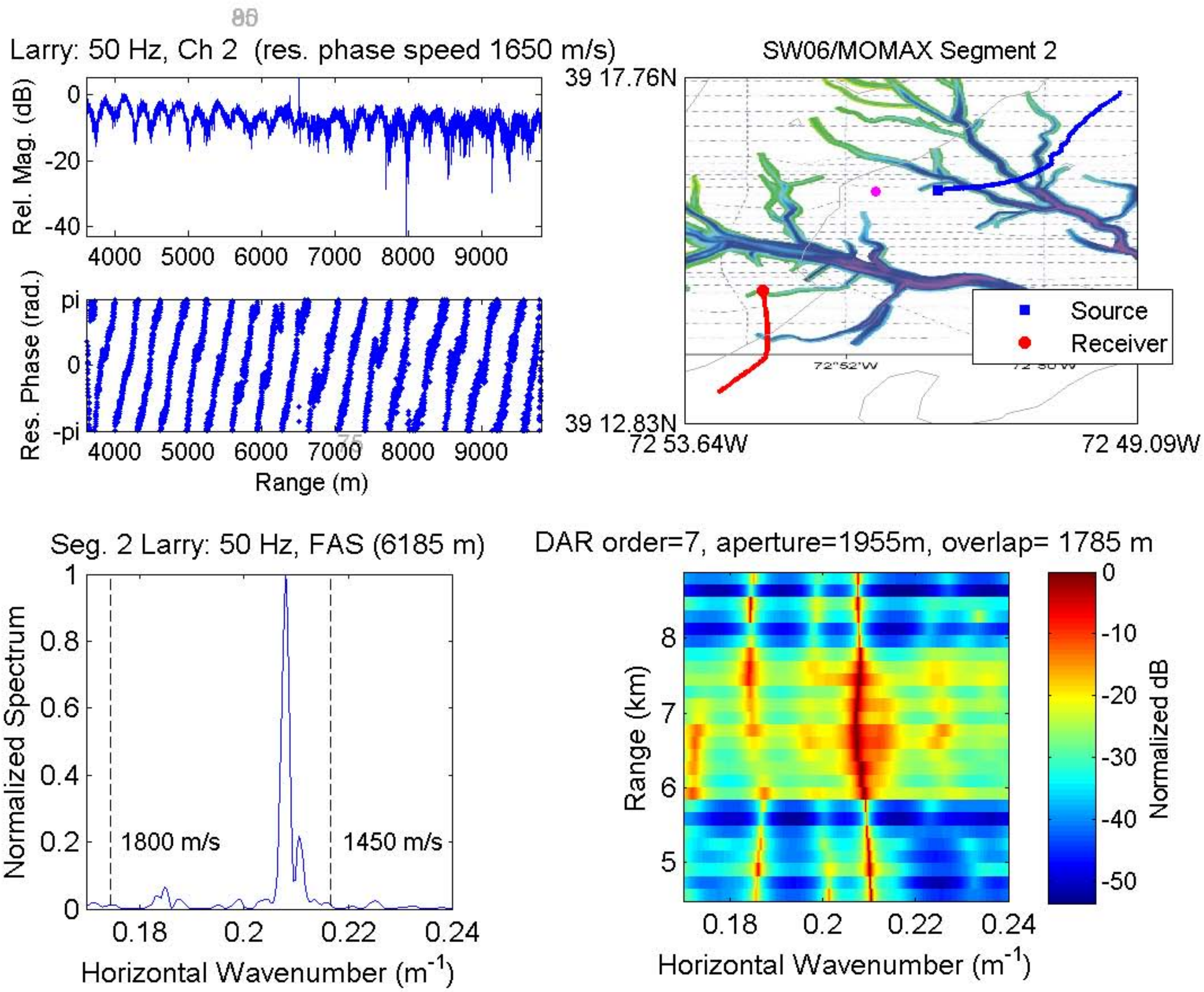

Figure 5: Summary of 50 Hz data received on Larry (range segment 2, hydrophone @ 43 m): pressure magnitude and phase vs range (upper left), source and receiver tracks superimposed on subbottom channel locations (upper right), normalized wavenumber spectrum for entire range aperture (lower left), autoregressive wavenumber spectrum vs range (lower right).

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HONORS/AWARDS/PRIZES

G.V. Frisk, Vice President of the Acoustical Society of America.